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Interdecadal variability of ENSO in 21 IPCC AR4 coupled GCMs

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[1] This study evaluates the interdecadal variability of El Nino/Southern Oscillation (ENSO) in 21 coupled general circulation models (CGCMs) participating in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). 110 years of the Climate of the 20th Century (20C3M) simulations are analyzed using wavelet analysis. The results show that the state-of-the-art CGCMs display a wide range of skill in simulating the interdecadal variability of ENSO. The 21 models can be categorized into three groups. The first group (8 models) shows an oscillation with a constant period shorter than the observed ENSO period, and sometimes with a constant amplitude. The second group (5 models) does not produce many statistically significant peaks in the ENSO frequency band, but usually produces one or two prominent peaks (episodes) at period longer than 6 years. The third group (8 models) displays significant interdecadal variability of ENSO in both amplitude and period. Among them, only the MPI model reproduces the observed eastward shift of the westerly anomalies in the low-frequency regime.
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1. Introduction

[2] Many observational studies have shown that the El Nino/Southern Oscillation (ENSO) displays significant interdecadal variability in its amplitude, period and onset time [e.g., *Gu and Philander*, 1995; *Wang*, 1995; *Mak*, 1995; *Wang and Wang*, 1996; *Torrence and Compo*, 1998]. Several theories have been developed to explain ENSO's interdecadal variability, such as oceanic teleconnections [e.g., *Gu and Philander*, 1997; *Kleeman et al.*, 1999], atmospheric teleconnections [e.g., *Barnett et al.*, 1999] and structure of the coupled mode [e.g., *An and Wang*, 2000]. From observational data, *An and Wang* [2000] found that the frequency change of ENSO is accompanied by a significant change in ENSO structure with an eastward shift of the westerly anomalies in the low-frequency regime. They further use a theoretical model to demonstrate the underlying physical mechanism based on the relative contribution of the thermocline feedback and zonal advection feedback.

[3] Many studies have evaluated the ENSO simulations of coupled general circulation models (CGCMs) [e.g., *Delecluse et al.*, 1998; *Latif et al.*, 2001; *Davey et al.*, 2002; *AchutaRao and Sperber*, 2002, 2006]. However, the ability of CGCMs to simulate ENSO's interdecadal variability has not been evaluated. This is important because if there are some CGCMs that can simulate the interdecadal variability of ENSO, they may help us to understand the physical mechanism of this variability.

[4] Recently, in preparation for the Inter-governmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), more than 20 state-of-the-art CGCMs produce a comprehensive set of long-term simulations for both the 20th century's climate and different climate change scenarios in the 21st century. The purpose of this study is to evaluate the simulations of ENSO's interdecadal variability in 21 IPCC AR4 CGCMs. The models and validation datasets used in this study are described in section 2. The diagnostic methods are described in section 3. Results are presented in section 4. A summary and discussion are given in section 5.

2. Data and Method

[5] This analysis is based on 110 years of the Climate of the 20th Century (20C3M) simulations from 21 CGCMs [e.g., *Boyle*, 2006; *Lin*, 2007; *Lin et al.*, 2006]. See *Lin* [2007, Table 1] for the model names and acronyms, their horizontal and vertical resolutions, and brief descriptions of their deep convection schemes. For each model we use 110 years of monthly mean surface skin temperature (SST).

[6] To sample the uncertainties associated with SST measurements/retrievals, we use two different observational datasets to validate the model simulations: (1) the Extended Reconstruction of SST (ERSST) [*Smith and Reynolds*, 2004], and (2) the Met Office Hadley Centre's Sea Ice and SST (HADISST) [*Rayner et al.*, 2003]. Both datasets are monthly data covering 110 years (1890–1999) with a horizontal resolution of 1 degree longitude by 1 degree latitude.

[7] Following the previous observational studies [e.g., *Gu and Philander*, 1995; *Wang*, 1995; *Mak*, 1995; *Wang and Wang*, 1996; *Torrence and Compo*, 1998], the interdecadal variability of ENSO is examined using wavelet analysis. Wavelet analysis is a powerful tool for analyzing multi-scale, nonstationary processes. Its uniqueness is its ability of simultaneously localizing the variability of the signal in both the frequency and time domains by using generalized local base functions (wavelets) that can be stretched and translated with a flexible resolution in both frequency and time [e.g., *Mak*, 1995; *Torrence and Compo*, 1998]. In other words, one can determine both the dominant modes of variability and how those modes vary in time. We utilize the wavelet analysis program developed by *Torrence and Compo* [1998] and use the Morlet wavelet as the mother wavelet.

3. Results

[8] Before conducting the wavelet analysis, we first look at the normalized Fourier spectrum of the Nino3 SST

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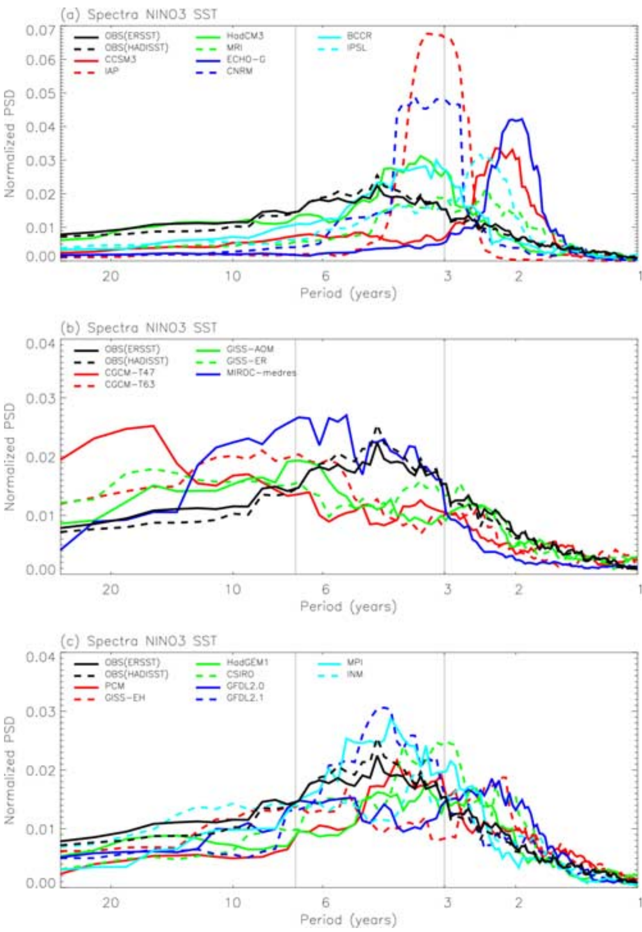

Figure 1. Normalized Fourier spectrum of Nino3 SST for two observational datasets and 21 IPCC AR4 CGCMs (plotted in three different panels).

(averaged between 5N–5S, 90W–150W) in both observations and the 21 IPCC AR4 CGCMs (Figure 1). The observed ENSO is a broadband phenomenon with a wide spectral peak between period 3–6 years. The simulations of the 21 CGCMs can be categorized into the following three groups: (1) the first group (Figure 1a) including 8 models (CCSM3, IAP, HadCM3, MRI, ECHO-G, CNRM, BCCR, and IPSL) which display a pronounced spectral peak with period shorter than the observed ENSO period; (2) the second group (Figure 1b) including 5 models (CGCM-T47, CGCM-T63, GISS-AOM, GISS-ER, and MIROC-medres) which have most of their variances distributed at period longer than 6 years; and (3) the third group (Figure 1c) including 8 models (PCM, GISS-EH, HadGEM1, CSIRO, GFDL2.0, GFDL2.1, MPI, and INM) which produce a relatively good spectral peak of ENSO. It is important to note that the category boundaries are not necessarily clear-cut. For example, GFDL2.0 sits somewhere between category 1 and category 3.

[9] Next we look at the wavelet spectrum of Nino3 SST (Figure 2). Only power above the 95% confidence level is plotted. In observations (Figures 2a and 2b), ENSO displays significant interdecadal variability in its amplitude and period. The amplitude is large before 1915, small between 1915–1950, and large again after 1950. The dominant period is about 3 years before 1910, 4–7 years between 1910–1965, 3–4 years between 1965–1980, and 4–5 years after 1980. These are consistent with the results of many previous studies [e.g., *Gu and Philander*, 1995; *Wang*, 1995; *Mak*, 1995; *Wang and Wang*, 1996; *Torrence and Compo*, 1998].

[10] The above three groups of models display different characteristics in their wavelet spectra. The first group of models generally shows an oscillation with a constant period shorter than the observed ENSO period, sometimes also with a constant amplitude (e.g. IAP, CNRM). The second group of models does not produce many statistically significant peaks in the ENSO frequency band, but usually produces one or two prominent peaks (episodes) at periods longer than 6 years (e.g. GISS-AOM, MIROC-medres). The third group of models generally displays significant interdecadal variability of ENSO in both the amplitude and period (e.g. CSIRO, MPI). For example, in the CSIRO model (Figure 2m), the ENSO period varies from 2 years in 1950–1960 to 6 years after 1980. Therefore, we do have a number of CGCMs that can produce interdecadal variability of ENSO. Again, it is important to note that the category boundaries are not necessarily clear-cut. For example, HadCM3 sits somewhere between category 1 and category 3.

[11] As discussed in the introduction, *An and Wang* [2000] found from observation that the frequency change of ENSO is accompanied by a significant change in ENSO structure with an eastward shift of the westerly anomalies in the low-frequency regime. Does this shift exist in some of the models with interdecadal variability of ENSO? Figure 3a shows the linear correlation with respect to the Nino3 SST anomaly for SST anomaly (solid) and zonal wind stress (ZWS) anomaly (dashed) along the equator (5N–5S) for the MPI model. The black lines are for model years 1960–1979 (low-frequency regime; see Figure 2s), the red lines are for model years 1980–1999 (high-frequency regime), and the blue lines are for model years 1940–1959 (another high-frequency regime). Amazingly, Figure 3a looks quite similar to Figure 2 of *An and Wang* [2000], and the MPI model does reproduce the eastward shift of the westerly anomalies in the low-frequency regime. Therefore, the MPI CGCM may be used to study the physical mechanism of this structure change to see if it is consistent with the theoretical model of *An and Wang* [2000], although some cautions need to be taken because the MPI model has the double-ITCZ problem [*Lin*, 2007]. Apart from the MPI model, no other models in category 3 produce the phase shift (Figures 3b–3h). It would be interesting to study why the MPI model behave differently from other models.

4. Summary

[12] This study evaluates the interdecadal variability of ENSO in 21 IPCC AR4 CGCMs. 110 years of the 20C3M simulations are analyzed using wavelet analysis. The results show that the state-of-the-art CGCMs display a wide range of skill in simulating the interdecadal variability of ENSO. The 21 models can be categorized into three groups. The first group (8 models) shows an oscillation with a constant period shorter than the observed ENSO period, sometimes also with a constant amplitude. The second group (5 models) does not produce many statistically significant peaks in the

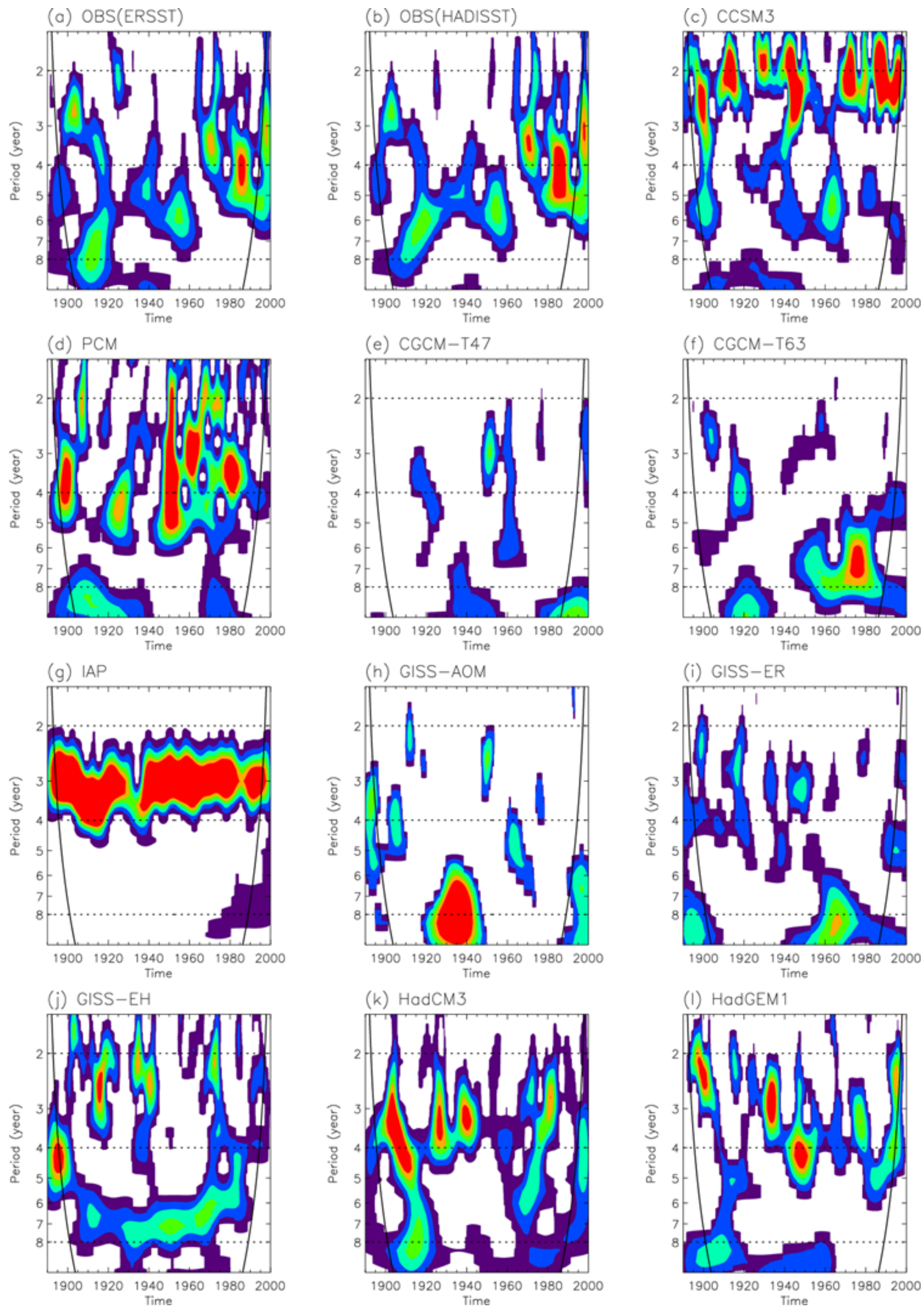

Figure 2. Normalized wavelet spectrum of Nino3 SST for two observational datasets and 21 IPCC AR4 coupled GCMs. Only power above the 95% confidence level is plotted. See scale bar on the next page.

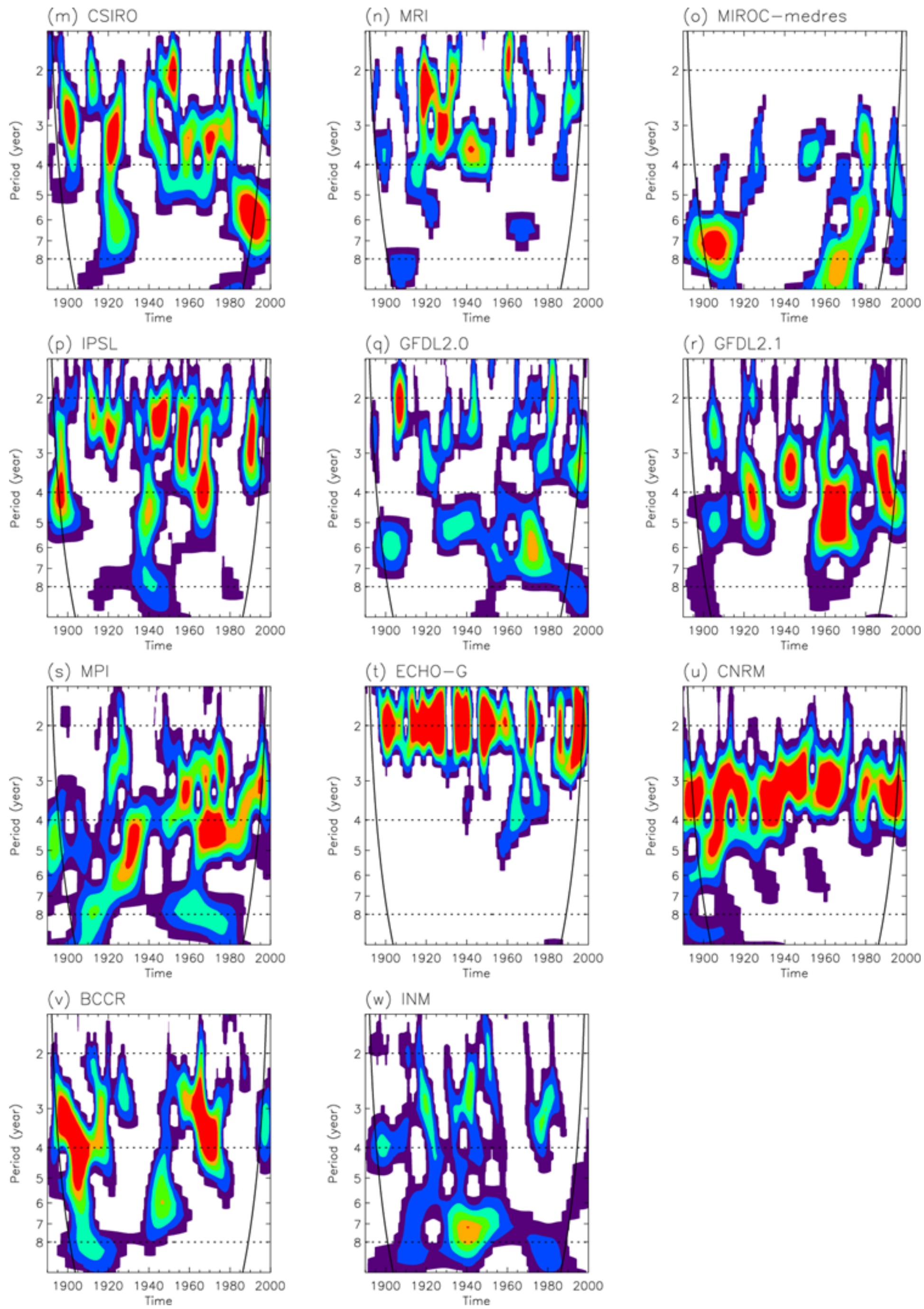

Figure 2. (continued)

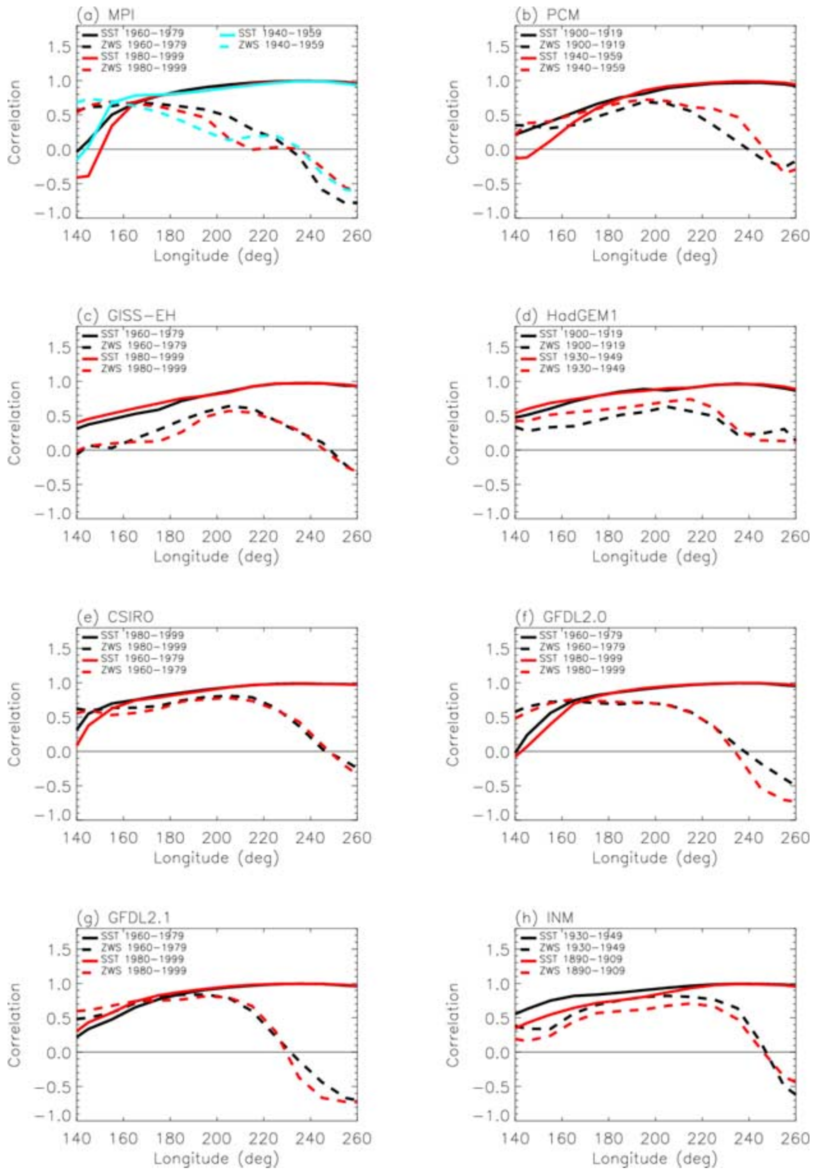

Figure 3. Linear correlation with respect to Nino3 SST anomaly for SST anomaly (solid line) and zonal wind stress (ZWS) anomaly (dashed line) along the equator averaged between 5N–5S for the eight models in category 3. The black lines are for low-frequency regime, while the color lines are for high-frequency regime.

ENSO frequency band, but usually produces one or two prominent peaks (episodes) at period longer than 6 years. The third group (8 models) displays significant interdecadal variability of ENSO in both amplitude and period. Therefore, we do have a number of CGCMs that can produce the interdecadal variability of ENSO. Among these models, only the MPI model reproduces the observed eastward shift of the westerly anomalies in the low-frequency regime.

[13] These results are very encouraging because detailed analysis of the third group of models, and in-depth intercomparison among the three different groups may help us to understand the physical mechanism for the interdecadal variability of ENSO.

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